The All-Variable WN8 Stars: the Stellar Core as Driver

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Abstract: As a continuation of our all-sky survey of the 'enigmatic' variable WN8 stars, we have carried out coordinated multi-site spectroscopic and photometric observations of three WN8 stars in 1995. These include WR123, WR124 and WR156. Combining the data with previously obtained simultaneous spectroscopy and photometry of another WN8 star, WR40, we confirm the lead of the stellar core in restructuring the whole wind. This emerges as a *statistical* trend: the higher the level of the ~continuum (i.e. ~core) light variations, the higher the variability of the P Cygni edges of the optical emission lines. However, a direct time correspondence between the light and profile variations might have a different form for each individual star.

1 Introduction

The WN8 stars form a distinct group in the Wolf-Rayet family, having *the lowest* percentage of confirmed binaries and avoiding clusters (runaway?). Nevertheless, they consistently demonstrate *the highest* level of spectral, photometric and polarimetric variability among the presumably single WR stars (Lamontagne & Moffat 1987; Moffat 1989; Robert et al. 1989). Attempting to complete our all-sky variability survey of the brightest WN8 stars (Antokhin et al. 1995; Marchenko et al. 1994), we present here the results of ~simultaneous photometry and spectroscopy of WR 40, 123, 124 and 156.

2 Observations

We obtained 10 nights of photometry (Stroemgren b,y) plus 3 nights of spectroscopy (spectral resolution $\Delta\lambda$=0.2Å; S/N$\geqq$200) for WR40 in 1989 using the 3.6m and 0.5m telescopes of ESO (Chile). The remaining 3 stars were observed photometrically for 1 month in 1994 and 2 months in 1995 (2-site broadband V photometry: 0.84m telescope of the San Pedro Martir Observatory,

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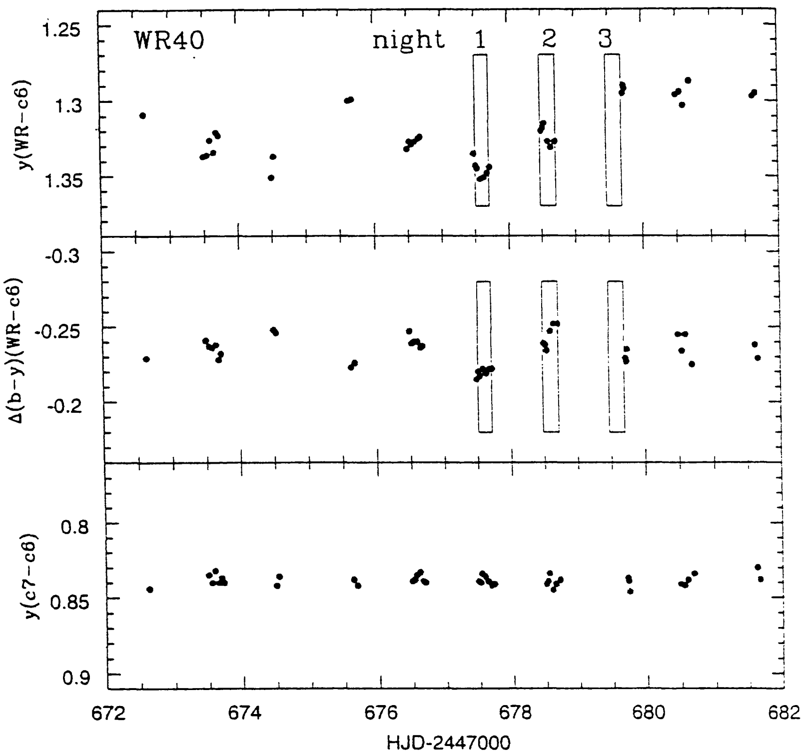

Figure 1a: Light curves (~continuum) of WR 40; Stroemgren b,y photometry. Thin-line boxes denote the times during which high-resolution spectra were obtained

México, and 0.6m telescope, Crimea, Ukraine), plus several weeks of spectroscopy ($\Delta\lambda$ ~5Å; S/N≳200 from 2 sites: 1.6m telescope of the Observatoire du Mont Mégantic, Canada, and 1.8m telescope of the Dominion Astrophysical Observatory, Canada), unevenly distributed through May to October 1995.

3 Results

The light curves of WR 40 (for a long-term overview see Matthews & Moffat 1994), WR 123, 124, 156 (Fig 1 a-d) show different scales of activity, which probably reflect the varying complexity of the oscillations. Intrinsic variability, expressed in terms of rms deviations ($\sigma(V)_{net}$: Lamontagne & Moffat 1987), ranges from 0.031 mag (WR 40), 0.029 mag (WR 123) to 0.016 mag (WR 124, 156).

The values of $\sigma(P)_{net}$ (fluctuations in polarized light: Robert et al., 1989) are grouped around $\sim (0.1 - 0.15)\%$, i.e. $\frac{\sigma(P)_{net}}{\sigma(V)_{net}} \sim 0.03 - 0.1$. The variations of WR 40 could result from an interaction of 2 periodicities (as well as their harmonics), namely f=0.057 d^{-1} and 0.081 d^{-1} (Matthews & Moffat 1994). We found *at least* 3 dominating frequencies in the light curve of WR 123 during 1994-1995: f_1=0.295, f_2=0.338, f_3=1.394 ($\pm$0.002d^{-1}). However, about 50% of the power escapes any attempt of fitting by periodic functions, revealing a significant *stochastic* component, always present in the light variations. This percentage of stochastic variability is epoch-dependent in WR 40, ranging from 20% to 70% . The light curves of WR 124 and WR 156 are relatively simpler, being defined by the (currently?) dominating frequencies f_1=0.225

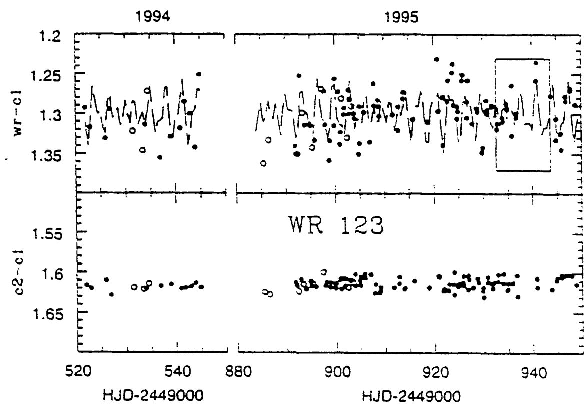

Figure 1b: WR 123; broadband (V) photometry. Dashed line is the sum of 3 sinusoids (see text). Open dots mark the data obtained at Crimea (Ukraine). Filled dots correspond to the San Pedro Martir (México) observations. Thin-line box defines the dates of simultaneous spectroscopy

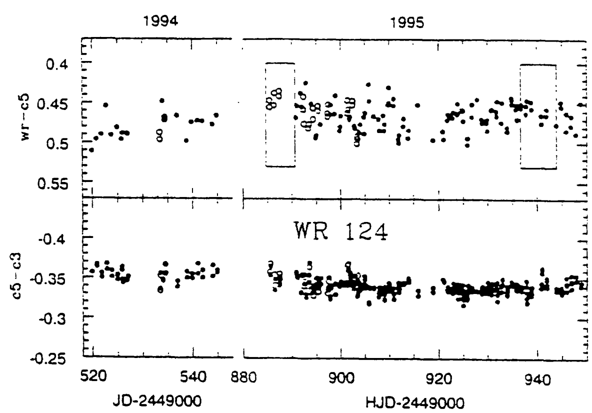

Figure 1c: the same as Fig 1b, but for WR 124

and f_2=0.587 d^{-1} for WR 124, and a single periodicity with f_1=0.064 (or 0.069 d^{-1}, depending on the comparison star used) for WR 156.

The spectroscopy (excluding WR 40: too few data) reveals no significant radial velocity variations for WR 123 and WR 156, and a weak hint of low-amplitude periodicity in WR 124, with $f_1=0.053\pm0.007 d^{-1}$ (A$\simeq$10 km/s in HeII lines and A$\simeq$7 km/s in HeI), and less probable, f_2=0.084 d^{-1}.

More interesting is the direct connection of the line profile variations (*lpv*) to the continuum changes. We can safely treat all observed V-band variations as continuum-related: the emission line content does not exceed 5-7% of the total V-band flux. However, we are able to derive only a *statistical* dependence: **the higher the level of continuum variations, the higher the spectral activity**. The *lpv* are mainly restricted to the P Cygni absorption troughs of HeI and (to a less extent) HeII lines.

Night-to-night *lpv* are perfectly synchronized in HeI and HeII (Fig. 2,3). Once the absorption significantly increases at $v \sim (v_\infty/2 \rightarrow v_\infty)$, the emission part only slightly decreases at $v \sim 0$. This somewhat reminds one of the *lpv* of EZ CMa (T. Morel et al., these proceedings).

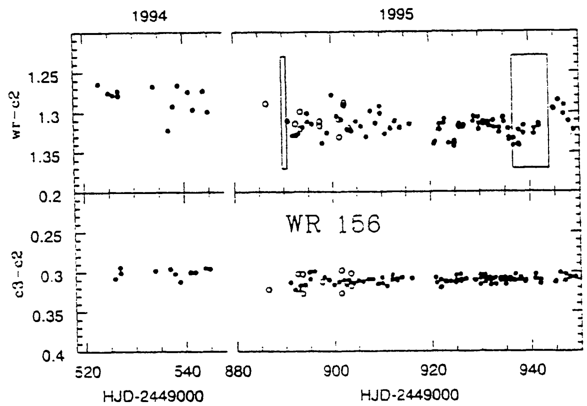

Figure 1d: the same as Fig 1b, but for WR 156

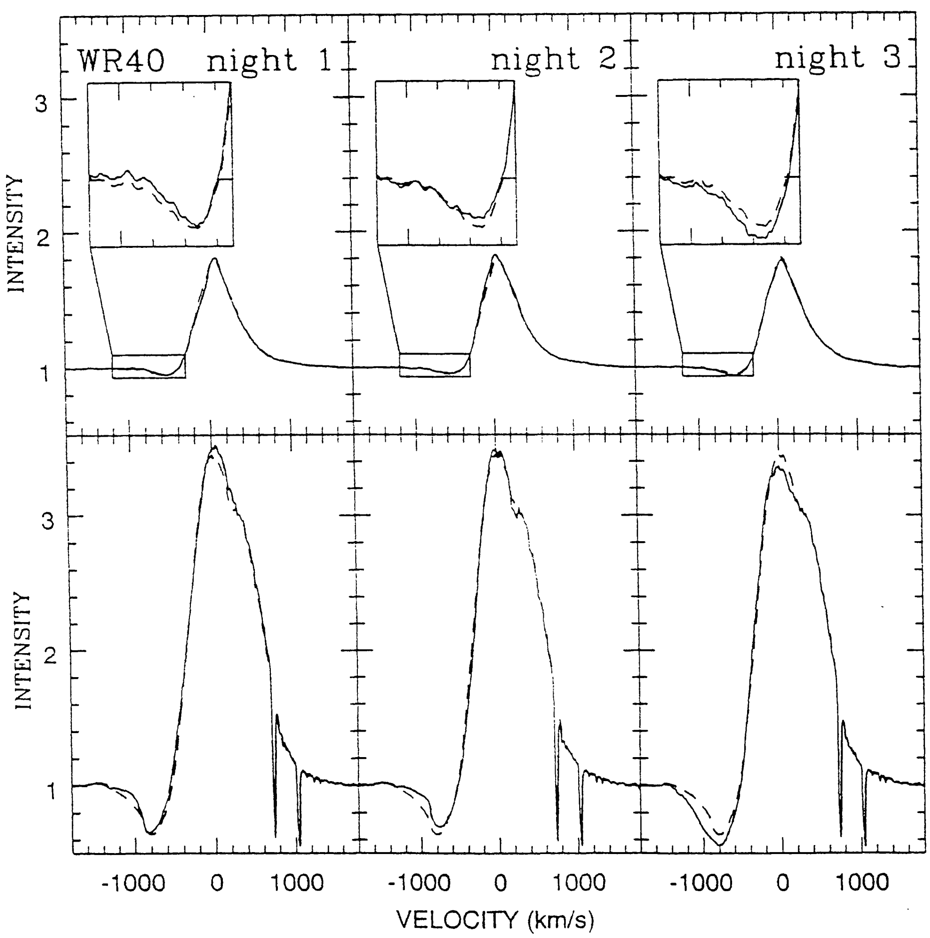

Figure 2: Night-to-night variations of WR 40. Upper panels: HeII λ 5412Å profiles. Lower panels: HeI λ 5876Å. Dashed line denotes the general mean profile; solid line marks the nightly means

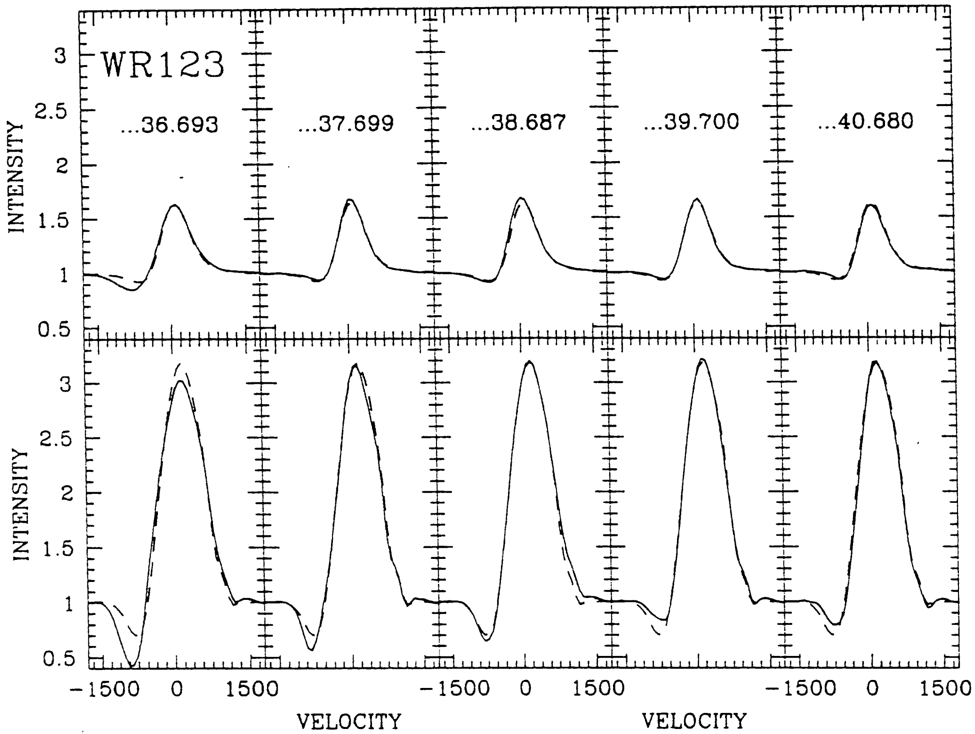

Figure 3: The same as Fig. 2, but for WR 123

Lack of pronounced variations of the emission parts of the profiles, as well as the good time consistency of the HeI and HeII absorption variations, point toward the ever-changing continuum flux as a driver of such night-to-night variability.

The situation is far more complicated in the case of the ~hourly, short-term *lpv*. We readily detect swift changes of the HeII absorptions, while the absorptions of HeI remain ~ constant on this time scale (Fig. 4). This complete desynchronization can be understood if one assumes that: (a) the HeI absorption is saturated - which is not the case, at least for WR 123; (b) all observed P Cygni variations take place at $v > v_\infty$. This would imply $v_\infty \sim 400$ km/s for WR 40 and $v_\infty \sim 600$ km/s for WR 123, which is (2-3)$\times$ lower than typical v_∞ for WN8 stars. (c) The last conceivable explanation calls for a non-monotonic velocity law - an assumption which would lead to acceptance of a companion braking the pace of the WR wind acceleration. But binary behaviour remains unconfirmed.

4 What Makes the WN8 Stars So Violent?

Currently we can consider 4 possible agents that could lead to the high level of variability, with preference for the last:

(1) Binarity. All periodicities emerging from photometry, spectroscopy or polarimetry are completely inconsistent, with strong epoch dependency and hints of multi-periodicities. The only promising cases are: WR 40, WR 66 and WR 124 (the latter being the weakest).

(2) Micro-structures in a WR wind ("blobs") can account for $\sim (5-10)\%$ (at the most!) of the observed $\sigma(V)_{net}$. The dilemma of small $\frac{\sigma(P)_{net}}{\sigma(V)_{net}} \sim 0.05 - 0.1$ (Richardson et al. 1996) can not be solved by assuming (non-polarized) continuum emission arising from the dense blobs: in WR 40 the flux variations show *decreasing* amplitude toward the infrared (Smith et al. 1985),

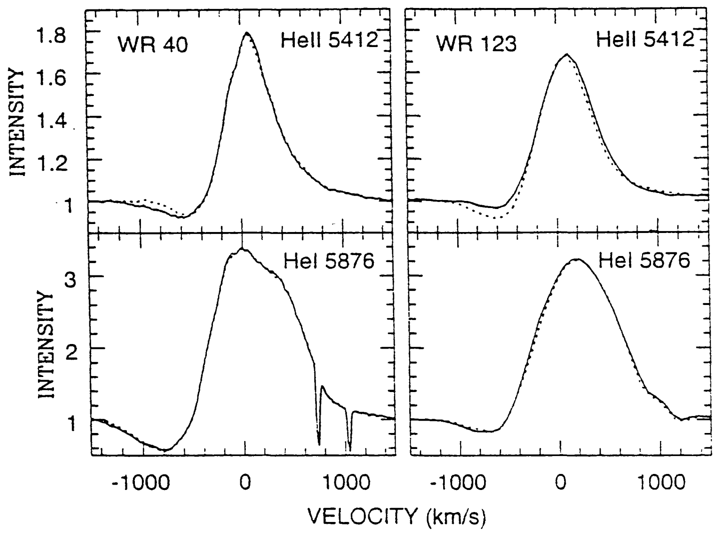

Figure 4: Short-term HeII variations. Left panels: HeII λ 5412 A vs. HeI λ 5876Å in WR 40. Right panels: WR 123. The profile marked by a dotted line was obtained 2-4 hours after the full-line profile. Note the different plotting scales for HeI and HeII

in contrast to expected growth due to free-free emission; also, the amplitude of the variations *is not* enhanced at the Balmer limit (Matthews & Moffat 1994), despite the presence of some hydrogen in the WR40 wind.

(3) The higher hydrogen content of the WN8 stars (relative to WNE stars) can only cause a decrease of the variations, as the plot of the decreasing $\sigma(V)_{net}$ with increasing H% shows for WN 7-8 stars.

(4) The most natural source and driver of the variations (~50% regular, ~50% stochastic) might be a stellar core generating multi-mode oscillations, being further transformed (enhancing; 'truncating' the coherency time?) and transported by surrounding optically thick WR wind.

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